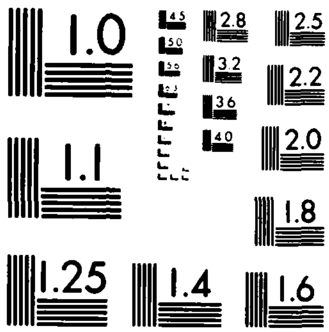
AD-A149 998 STATISTICAL ANALYSIS OF HELICOPTER PILOT PERFORMANCE DURING INSTRUMENT FL..(U) JACKSONVILLE STATE UNIV AL DEPT OF PSYCHOLOGY D J FOLDS ET AL. 15 SEP 83 1/1

UNCLASSIFIED DAMD17-81-C-1174 F/G 5/9 NL

END

FILMED

DTIC



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS 1963 A

(1)

AD ______________________

STATISTICAL ANALYSIS OF HELICOPTER PILOT PERFORMANCE DURING INSTRUMENT FLIGHT ACROSS REPEATED FLIGHTS

ANNUAL AND FINAL REPORT

Dennis J. Folds

Gary W. Yunker

T. Allen Smith

September 15, 1983

Supported by

U.S. Army Medical Research and Development Command

Ft. Detrick, Frederick, Maryland 21701-5012

Contract No. DAMD17-81-C-1174

Jacksonville State University

Jacksonville, AL 36265

The findings in this report are not to be construed as an official Department of the Army position so designed by other authorized documents.

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER	2. GOVT ACCESSION NO. AD-A149
3. RECIPIENT'S CATALOG NUMBER 998	
4. TITLE (and Subtitle) STATISTICAL ANALYSIS OF HELICOPTER PILOT PERFORMANCE DURING INSTRUMENT FLIGHT ACROSS REPEATED FLIGHTS	5. TYPE OF REPORT & PERIOD COVERED ANNUAL AND FINAL REPORT (15 Sept. 81 - 30 Sept. 83)
	6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Dennis J. Folds, Gary W. Yunker, T. Allen Smith	8. CONTRACT OR GRANT NUMBER(s) DAMD17-81-C-1174
9. PERFORMING ORGANIZATION NAME AND ADDRESS Jacksonville State University, Department of Psychology, Jacksonville, AL 36265	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 62777A-3E162777A879-BG-101
11. CONTROLLING OFFICE NAME AND ADDRESS U.S. Army Medical Research and Development Command, Ft. Detrick, Frederick, MD 21701-5012	12. REPORT DATE September 15, 1983
	13. NUMBER OF PAGES 44
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)	15. SECURITY CLASS. (of this report) Unclassified
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approval for public release; distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Performance (Human), Instrument Flight, Fatigue, Eye Movements, Helicopter Pilot Performance

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Data from week-long simulated extended operations study were examined with respect to methodological issues associated with the assessment of helicopter pilot performance (including visual performance) and the potential impact of extended flight schedules on pilot performance. No significant changes in pilot performance over the week of extended operations were found. Methodological issues are discussed and recommendations for future studies are offered.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

Figure 2

85 01 22 007

20. Data from week-long simulated extended operations study were examined with respect to methodological issues associated with the assessment of helicopter pilot performance (including visual performance) and the potential impact of extended flight schedules on pilot performance. No significant changes in pilot performance over the week of extended operations were found. Methodological issues are discussed and recommendations for future studies are offered.

TABLE OF CONTENTS

LIST OF TABLES

SUMMARY

Eye movement data and system performance data collected in a flight simulator during a helicopter pilot fatigue study were analyzed. It was found that 80% of the pilot's visual time during instrument flight is spent fixated on seven cockpit instruments. A factor analysis of the dependent variables calculated from eye movement data revealed two orthogonal factors: the relative importance of an instrument and the central tendency of the dwell times for that instrument. The eye movement data revealed no significant changes during the course of the fatigue study. There were significant differences in the use of several instruments as a function of maneuver. The analysis of the system performance data also revealed no changes during the course of the fatigue study. Factor analyses of the system performance data revealed that during cruise flight the measures of system stability are all highly correlated whereas during instrument take-off the stabilities of the pitch, roll, and yaw axes are essentially uncorrelated. During instrument landing the pitch and roll values are highly correlated with one another but are only moderately correlated with the yaw/heading values. The implications of the present methodological analyses are discussed with respect to future assessments of helicopter pilot performance. The lack of significant differences in performance in the present study as well as previous studies are considered indicative of the resistance of a helicopter pilot's flight proficiency to degradation during relatively short-term fatigue studies and it is suggested that future studies incorporate secondary tasking to provide a more sensitive and realistic assessment of the impact of extended flight schedules.

The relative importance of the helicopter in the operations of the U.S. Army has drastically changed over the past three decades. Whereas in earlier times the helicopter was primarily used for medical evacuation and routine transportation missions, the helicopter is now an integral component in a wide variety of tactics; its missions include weapons delivery, reconnisance, and forward area placement of troops and supplies. The envisioned scenario for another ground war in Europe is one in which intense, around-the clock operations would be conducted for a period of several days to weeks. During this time helicopter pilots would likely be required to fly on an extended flight schedule, that is, fly many hours per day with relatively little rest. A potential problem that could seriously hinder mission accomplishment during these operations is helicopter pilot fatigue. Although "fatigue" has proven to be a term that is difficult to precisely define, its detrimental impact, both on operational efficiency and accident rate, has been an area of concern for some time (Perry, 1974; Krueger and Fagg, 1981). One of the key issues on this area is the potential effect of fatigue on helicopter pilot performance.

In response to the many questions surrounding the effects of extended flight requirements, investigators at the U.S. Army Aeromedical Research Laboratory (USAARL), Ft. Rucker, AL, conducted a research project designed to simulate extended operations (Krueger, Armstrong, and Cisco, 1980). Six volunteer subjects flew various mission profiles in a flight simulator over a one week period. The one week period consisted of a pre-test day, five test days, and a post-test (recovery) day. As part of the routine observed during the five test days, each day a subject performed a set of standard flight maneuvers while wearing the National Aeromedical Corps (NAC) eyemark equipment used by USAARL investigators to record the visual behavior of aviators (see Simmons, Kimball, & Diaz, 1976). The maneuvers were instrument take off (ITO), cruise flight (CRUISE) and instrument landing (ILS). The maneuvers were performed at approximately the same time each day to reduce any within-day effect that might be present. The data collected during these maneuvers included real-time sampling of the pilot's visual behavior, control inputs, and system performance. These data were processed, reduced, and verified by USAARL personnel in accordance with in-house procedures. The analysis of the resulting summary statistics for each flight segment is the focus of the present research. The present project was conducted in two phases: Phase I dealt with the visual performance data and Phase II dealt with the system performance data. Each phase was characterized by an exploratory approach to data analysis. Initially, the several dependent variables computed for each exploratory factor analysis was used to assess the relationships among the variables. The result of these procedures was the selection of variables for analysis of variance (ANOVA) in order to inferentially test for a change in performance across days.

Additionally, during Phase I the findings of previous studies of helicopter pilot visual performance during instrument flight rule (IFR) conditions were compared with the present visual performance data for purposes of replication. Also, during Phase II, the relationship between visual performance and concurrent system performance was examined. The approach and results for each phase will be presented separately.

The purpose of the present research was more than a simple analysis of previously collected data. The data in both phases were used as a base for the assessment and, where necessary, the development of statistical methodology used in studies of helicopter pilot performance. This sort of work is necessary in that specialized, application-oriented research must often proceed without the "history" of basic laboratory tasks. Indeed, the selection of experimental tasks and the strategy used in assessing performance on those tasks are issues of vital importance in relatively new areas of research. It is hoped that the present project will help address those issues and thereby contribute to the theoretical foundations of research in helicopter pilot performance.

Phase I: Visual Performance

Background

Measures of a helicopter pilot's visual behavior during a flight segment may be computed for designated areas within the pilot's visual field. In the present context, the designated areas were the individual cockpit instruments in USAARL's flight simulator. These instruments are listed in Table 1. The visual area labeled "Rest" in Table 1 represents all areas not included in the instruments, and it should be noted that the flight simulator did not include a projected external scene. There was nothing "outside" the aircraft for the pilot to view except a translucent screen, thereby simulating instrument flight rule (IFR) conditions. The IFR condition has been suggested to be a major contributor to pilot fatigue (Perry, 1974).

For each designated area within the visual field, there are two basic phenomena of interest: the number of times the area was fixated and the amount of time spent fixated on the area (dwell time). These basic measures may be converted to a more standard scale (e.g. percent of total fixations or percent of total time). The seven dependent variables for visual performance used by Simmons, Lees, and Kimball (1978) are shown in Table 2 and were used in the present research as a starting-point for a methodological evaluation of assessing visual performance.

An initial examination of the visual behavior of helicopter pilots during instrument flight was reported by Simmons, et al (1978). The principle findings of that report may be summarized as follows:

1. The vast majority of visual time during instrument flight is spent fixated on seven

cockpit instruments: the altimeter (ALT), vertical speed indicator (VSI), attitude indicator (AH), radio magnetic indicator (RMI) omni-bearing selector (OBS) airspeed indicator (AS), and turn and bank indicator (T&B).

2. The AH and RMI combined account for over one-half of total visual time, with the attitude indicator being used the most.

3. The mean dwell time for instruments with simple pointer systems such as the ALT, AS, and VSI was 400 to 500 milliseconds (msec) while more complex instruments such as AH and RMI required 500 to 600 msec.

4. The objective visual performance data greatly differed from the pilots' opinion of the importance of various instruments.

In the same report the authors offer a novel approach to the description of the visual workload of helicopter pilots. The major points of their "three zone/cost factor" theory are as follows:

1. The instrument panel may be divided into the three zones. Zone 1 consists of the AH, RMI, and T&B. This zone contains the information necessary to maintain the basic stability of the aircraft. Zone 2 consists of the ALT, VSI, and AS. This zone provides detailed information about current aircraft status. Zone 3 consists of all other areas, including the OBS. The information in the zone is essential only in special requirement situations. Otherwise Zone 3 is monitored on an "as time allows" basis.

2. The "cost factor" of each zone (with respect to visual workload) may be calculated as follows: (<u>percent of total time spent in the zone + percent of total fixations occurring in the zone</u>) divided by 2.

3. The cost factor of Zone 1 during a particular flight segment is an index of the amount of the pilot's attention necessary to maintain the basic stability of the aircraft.

4. ITO appears to require the most and ILS the least attention to Zone 1. The cost of the

zone during other maneuvers is somewhere in between these two extremes.

The primary intent of the zone/cost factor approach is to simplify the quantification of the visual performance of helicopter pilots. The computation of the cost factor variable combines the two basic measures of visual performance (number of fixations and total dwell time) into a single value which represents the "cost" of a particular area during a flight segment. Dividing the visual field into three zones instead of twenty to thirty instruments and guages (depending on the particular cockpit) and computing the cost factor for each zone allows a pilot's visual behavior during a particular flight segment to be represented by three values.

There are four points raised in the Simmons, et al (1978) study that may be seen as key issues in evaluating helicopter pilot visual performance. First, the finding that visual time during IFR flight is largely concentrated on seven instruments suggests that any significant change in visual performance will be associated with the usage of these seven instruments. Second, the observation that mean dwell time varies as a function of instrument complexity is important in establishing this variable as a measure of visual performance, rather than a simple artifact of calculations that may be performed on any set of numbers. Third, the assertion that cost factor combines the salient information from other measures of visual performance into a single value that represents percent of workload certainly has implications in the selection of dependent variables to represent pilot visual performance. (The computation of cost factor need not be limited to the three zones specified above. It may be computed for individual instruments and its viability as the dependent variable of choice is not contingent upon the credibility of the three zone theory). Fourth, the notion that the pilot's visual field may be represented by three zones has clear implications for procedures to be used in assessing visual performance and in making comparisons across settings, aircraft, maneuvers, individual pilots, and workload conditions. It should be noted that the two components of the three zone/cost factor theory were considered as conceptually distinct issues in the present context.

Approach

Each of the four key points discussed above were examined before any between-maneuver or across-days effects were assessed. In particular, the percent of total time and mean dwell times for each instrument were calculated without respect to maneuver or day. These values were then compared with the values reported by Simmons, et al (1978), in the context of a cross-validation check on those previously reported values. As the results of these procedures were generally affirmative (see below), the dependent variables listed in Table 2 were factor analyzed for each of the seven primary instruments separately. Factor rotation was accomplished using the varimax procedure in cases where two or more factors with eigenvalues greater than 1.0 were obtained. The seven primary in-

struments were then factor analyzed in order to assess the grouping of instruments offered in the zone theory, under the assumption that if the theory is to be supported, then the use of instruments within a zone should be positively correlated whereas comparisons of instruments in different zones should reveal zero or negative correlations. The varimax procedure was again employed in factor rotation.

Results and Discussion

It was found that the seven instruments (AH, ALT, AS, OBS, RMI, T&B, and VSI) identified by Simmons, et al (1978) accounted for approximately 80% of total visual time in the present study. The other 18 instruments/guages in the simulator cockpit accounted for approximately 3%, all other areas ("Rest") accounted for about 7%, and the remaining 10% was transition (eye movement) time. The percent of total time for each instrument is presented in Table 3. Since "Rest" and transition are indiscriminant areas and the other 18 instruments accounted for only 3% of visual time, it appears that the seven instruments identified by Simmons, et al (1978) do indeed represent the essential visual tasks of pilots during IFR conditions. Based on these findings, the data from visual areas other than the seven primary instruments were excluded from further analyses.

The mean dwell times for each of the seven primary instruments are shown in Table 3. The general observation that the more complex instruments have higher, that is, longer, mean dwell times than instruments with simple pointer systems is supported by these data. However, the actual values of the mean dwell times tended to be slightly higher than the values previously reported. Simmons, et al (1978) reported that the simple instruments such as the ALT, AS, and VSI had mean dwell times in the 400-500 msec range. The mean dwell times for those three instruments were slightly above 500 msec in the present data; the mean dwell time for the T&B was the only one less than 500 msec. They also reported that the msec complex instruments such as the AH and RMI had mean dwell times on the 500-600 msec range. In the present study, the mean dwell time for the AH fell within that range, but the mean dwell time for the RMI was well over 600 msec and the mean dwell time for the OBS was nearly 700 msec. Note that the difference in mean dwell time for the VSI, a simple instrument, and the AH, a more complex instrument, was only 20 msec in the present data. The difference between the present values and the previously reported values were relatively small and could be due to differences between the cockpits, subjects, flight profiles, or simply sampling error. It does appear, however, that mean dwell time may be used as an index of the complexity of information presented on an instrument.

The seven dependent variables listed on Table 2 were factor analyzed for each of the primary instruments. Six of the seven instruments (the OBS being the exception) returned virtually identical two-factor solutions. The rotated solutions are presented in Table 4. Examination of

the rotated solutions reveals that four variables (percent of looks, scan rate, percent of time, and cost factor) had extremely high loadings on factor 1 while mean dwell time and median dwell time had high loadings on factor 2. It should be noted, anecdotally, that factor loadings of these magnitudes are relatively rare in factor analysis. The implications of these results are clear: the visual phenomena measured by the four variables with high loadings on factor 1 are conceptually similar, separate analyses of these variables would be largely redundant, and multivariate analyses performed on these variables would be troubled by high multicollinearity because these variables are so highly correlated. These variables seem to be measures of the relative importance of an instrument during a given flight segment. Furthermore, the information represented by mean and median dwell time is essentially uncorrelated with measures of relative importance; factors 1 and 2 are orthogonal. As discussed above, it appears that these variables reflect the complexity of an instrument. The one-factor solution obtained for the OBS affirms these observations. Data from all three maneuvers were included in these analyses. During ITO and CRUISE the OBS received occasional glances even though there was nothing to "read" on the instrument. During ILS, however, the OBS became active and was used a great deal in performing the simulated instrument landing. The dwell times and relative importance of the OBS were, therefore, positively correlated and thus a one-factor solution was obtained.

The remaining issue in the examination of the dependent variables involves the selection of variables representative of the two factors for further analysis. Scan rate and mean dwell time had the highest average loadings on factors 1 and 2, respectively (see Table 4), however, these differences were slight and at times were in the third decimal place. These decisions must be predicated on grounds other than the factor loadings. Of the four variables associated with factor 1, only the scan rate is not expressed as a percent. The difficulty with percent scales is that an arbitrary floor and ceiling (0% and 100%) are forced upon the data, often leading to a departure from normality, particularly when data values are at either extreme of the scale. Of course, this difficulty may be partially addressed by employing the square root arcsine transformation of the data. Scan rate represents essentially the same information as the other three variables and has no imposed ceiling; it was selected for further analysis. It should be noted that the normality of response rates is often suspect itself; however, a chi-square test for departure from normality was applied to the scan rates and failed to reach significance. The choice between mean and median dwell times must also be based on the normality of their respective distributions. The mean is generally preferable to the median of a distribution in that it is based on the interval properties of the data, whereas the median uses only the ordinal properties of the data. The exception is when the underlying distributions are skewed from normality; in such cases the median is often a better indication of central tendency and is itself more normally distributed than the mean. Although the reaction-time literature is replete with the mean vs median debate, we found no evidence

that eye-fixation times are decidedly non-normal. A chi-square test was also applied to the mean dwell times and failed to reach significance, and mean dwell time was selected along with scan rate for further analysis. It should be noted in this context that cost factor does not appear to be a variable that combines salient and distinct information into a single variable. Rather, it is the simple arithmetic average of two highly correlated variables and is subject to the difficulties associated with a percent scale. Cost factor has no apparent superiority as a measure of visual performance. It should also be noted that for descriptive purposes, values expressed in percent may be more meaningful than responses per minute, especially to readers less familiar with the area. We, therefore, use percent of total time (%TT) as the descriptive variable of choice in this report.

The division of the pilot's visual field into three zones, as shown in Table 5, was not supported by factor analysis. The scan rate values for each of the seven primary instruments during each flight segment were factor analysed to determine the grouping of the instruments which best accounted for the variance of the scan rates. The varimax procedure used in factor rotation seeks to maximize the loading of each variable (instrument) on one of the factors, i.e., each instrument has a high loading on one factor and near zero loadings on other factors. This analysis resulted in a three-factor solution which accounted for only 76% of the total variance. The rotated solution is presented in Table 6. The instruments which had high loadings on factor 1 were the VSI, AH, and OBS. The sign of the loading for the AH is negative. Further examination of the data revealed that the negative loading of the AH is largely due to subject differences in the performance of the ILS maneuver. This issue will be addressed below. The instruments with high loadings on factor 2 are the RMI and the T&B. The ALT and AS had high loadings on factor 3. Although there is some similarity between the factors and the zones shown in Table 5, there are also major differences. It is not accurate to state that the findings of the present research somehow disproved the zone theory; however, it is accurate to state that the theory was not supported empirically.

A more salient concern in evaluating the zone theory involves the meaningfulness of the values derived for the zones. The values in Table 7 illustrate the primary problem with the meaningfulness of zone values: knowledge of the value for the zone imparts very little information about visual behavior within the zone. The validity of the theory on this point rests on one crucial question: Does it matter which instruments within the zone are given visual time? If the collective monitoring of the instruments is critical but the specifics are not critical, then the theory may be valid. If the converse is true, the value for the zone may conceal important differences. According to the zone theory, the instruments within Zone 2 (ALT, AS, VSI) present "quality flight management" information which is monitored only when the monitoring of Zone 1 is not critical. Projecting this line of thought, monitoring of Zone 2 should be highest during cruise flight since ITO requires more effort in Zone 1 and ILS poses a naviga-

tion task which requires use of the OBS - a Zone 3 instrument. This observation is true for the ALT and the AS, but not for the VSI. In fact, the VSI was used almost twice as much during ILS than during ITO or CRUISE (see Table 8). Zone 3 consists of all visual areas not included in Zones 1 and 2. The primary problem with this arrangement is the inclusion of the OBS in the zone. Examination of the percent of time spent in Zone 3 indicates that during ILS the monitoring of Zone 3 becomes critical. This observation is misleading in that it is only the monitoring of one instrument in the zone - the OBS - which becomes critical during the ILS. Other instruments within the zone actually received only about one half the visual time that they received during ITO or CRUISE (again, see Table 8). The intent of the theory to simplify the task of describing visual behavior - is commendable. However, the lack of empirical support for the grouping arrangement, along with the instances cited where the zones values may be misleading, suggests that caution be taken in analysis of the zone values. Based on the findings presented above, the appropriate ANOVA was performed to assess the effects of maneuvers, days, and the maneuver by day interaction on the mean dwell times and scan rates for the seven primary instruments. Therefore, there were fourteen (seven instruments times two variables) ANOVAs performed. None of these fourteen analyses revealed any significant effects due to days or the maneuver by day interaction. All significant $\underline{F}$-ratios were associated with the maneuver effect.

The analyses of the scan rate data reveal that five of the seven instruments were used significantly more on certain maneuvers than in others. Only the AH and RMI showed no differences. The ANOVA tables for the five significant tests are presented in Tables 9-13. Since there were no significant day or maneuver by day interaction effects, the subsequent contrasts of means were performed by collapsing the data across days and computing the true scan rate of each instrument for each subject across the five test days. With the data expressed in this form the contrasts of means was accomplished by doing a series of simple t-tests for related measures. The significant contrasts are summarized in Table14.

Identical tests were performed on the mean dwell time values. These tests revealed that the mean dwell time for both the OBS and VSI were higher during ILS than during the other two maneuvers. The ANOVA tables for these two tests are presented in Tables 15 and 16. The other five instruments showed no differences in mean dwell time between maneuvers.

The observed differences between maneuvers were not surprising. Just as automobile drivers perform different tasks in different driving situations, helicopter pilots perform different tasks during different flight maneuvers. It is not surprising that certain instruments are more important in some maneuvers as opposed to other maneuvers. In general, analyses of the scan rates revealed no significant differences in the use of the AH and RMI, the two prominent instruments, while the use of the OBS and VSI increased during ILS and the use of the ALT, AS, and T&B decreased during ILS. The finding that the mean dwell time of the OBS was higher during ILS than during the other maneuvers is also not surprising since

the instrument presented no information to the pilot during ITO or CRUISE. The higher mean dwell time for the VSI during ILS is more puzzling. One possible explanation is that during ILS it is more important for the pilot to determine precisely at what rate the aircraft is decending, whereas during other maneuvers the instrument is read only to confirm a less specific range of the rate of change. If this explanation is correct then mean dwell time is not only a measure of the complexity of the instrument's design but also of the degree of accuracy required by the flight situation.

Further examination of the data revealed differences between subjects that affect the interpretation of the results presented above. A certain amount of variation between subjects is not only expected but is also desirable. The visual behavior of aviators during flight is complex and there is probably no single "correct" way of performing the visual tasks. Inherent limitations due to the limited availability of volunteer subjects, time, and incurred expenses generally result in a small number of subjects. Experimenters conducting these research projects must endeavor to obtain a representative sample of the population of aviators. When the data later reveal marked differences between subjects, experimenters are left to ponder whether a homogeneous population was in fact sampled or whether the variation within the population is so broad that the employment of such a small N can adequately sample the population. The presence of one or perhaps two deviant subjects poses relatively minor problems in data interpretation. However, in areas where subjects exhibit large and consistent differences in the performance of the behavior in question, interpretation of results is often quite difficult. Summary statistics such as these presented in Table 1 may be mere statisticial artifacts, that is, they may not represent the way subjects tended to perform, but instead represent the midpoint between two drastically different ways of performing the task. There were two particular areas of difference between subjects that are especially pertinent to the interpretation of the results. These two areas of differences are explored below.

As mentioned above, the negative correlation between the AH and the OBS is largely due to differences between subjects. Table 17 shows the %TT during ILS spent fixated on the AH, RMI, and OBS for each subject. Note that the values for the RMI were quite stable; only one value is outside the 20%-25% range. However, subjects greatly differed on the percent of time devoted to the AH and the OBS. Although the total values, collapsed across subjects, for the AH and the OBS are relatively close (19.1% and 21.2%, respectively), only subject 5 used the two instruments in a balanced manner. Subjects 1, 2, and 3 used the OBS far more than the AH. Subjects 4 and 6 used the AH far more than the OBS. Whether these differences reflect two equally successful strategies in the performance of the maneuver, differences in training or experience, or some other factor is unknown. It is apparent, however, that these differences affected the

factor analysis performed to address the grouping arrangement of the zone theory.

Another area of subject differences which is important has to do with the performance of the ITO maneuver. This maneuver, according to the zone theory, is the maneuver in which monitoring of Zone 1 instruments (AH, RMI, T&B) is most critical. Table 7 presents the %TT spent fixated on each of these instruments, and the total for zone 1, during ITO. Three subjects used the T&B less than five percent of total time while another subject used the instrument over fifteen percent of total time. The three subjects that used the T&B less than 5%TT differed from one another in their use of the AH and the RMI; one favored the RMI, one favored the AH, and the third used the AH and RMI in a relatively equal way. The point is that since subjects greatly differed in the use of the instruments within the zone, the value for the zone as a single entity is an artifact and actually reveals very little about the subject's behavior. (To illustrate this point, compare the values for subjects 3 and 4 in Table 7).

Differences between subjects affected the analyses performed in this project in various ways. The ANOVAs possibly become more liberal tests in that the large sum-of-squares value for the untestable subject effect are subtracted in the calculation of the error terms, perhaps resulting in inflated values of $\underline{F}$. The factor analyses reflect the subject differences and are therefore difficult to generalize to the aviator population. The major problem posed by the subject differences, however, is not their effect on the statistical analyses but rather their effect on the confidence which may be placed in the representativeness of the sample employed in this study.

Phase II: System Performance

Background

System performance variables may be computed with respect to the six flight parameters that characterize aircraft flight status at any given point in time: altitude, airspeed, heading, pitch, roll, and yaw. During a given flight segment, each parameter is periodically sampled. For flight segments where a parameter is supposed to be constant, the mean and standard deviation of the sampled values may be used to represent system performance. For flight segments where a parameter is supposed to change, some other calculation (such as the accuracy of the effected change or the variability of the rate of change) is usually more appropriate. In certain special flight segments, system performance may be measured with respect to some other reference; examples include deviation from glide slope during final approach and distance from a designated touchdown point (error) upon landing. In the present context, however, these special calculations are not relevant.

In a previous study of helicopter pilot performance during extended flight requirements, Lees, Simmons, Stone, and Kimball (1978) used pitch standard deviation, roll standard deviation, and heading standard deviation as measures of aircraft stability for a low-altitude rearward hover. They found no across-days effect manifested in these variables. Other studies have also assessed change in system performance over time, although not in the context of extended operations. For example, Hamilton, Folds, and Simmons (1982) used magnitude of error, parameter variability during straight and level flight, and time required to effect parameter changes as measures of system performance during a precision flight maneuver. That particular study was directed at performance changes associated with the onset of heat stress in helicopter pilots wearing chemical defense ensembles. They found no difference in performance across time.

In the present study, the system performance data from the same flight segments used in Phase I were obtained from USAARL. We were assured by USAARL personnel that the summary statistics for each performance of a maneuver were based on uniform segments of that maneuver, for example, the data summarized for ILS began shortly after the final turn, continued through the final approach, and ended upon touchdown. The only significant lack of uniformity was that different flight profiles had been used in the context of different mission scenarios. The means of the flight parameters were consequently not comparable because, for example, the instructed heading for CRUISE was not always the same. The standard deviations were comparable within a maneuver since each flight profile included each of the three maneuvers (ITO, CRUISE, and ILS) in a similar context, differing only in terms of absolute parameters such as heading. The standard deviations for each of the six flight parameters during each flight segment were therefore used as the starting point for the analyses of Phase II.

The principal issue addressed before the assessment of across-days effects involved the examination of the relationships among the flight parameters standard deviations for each maneuver. These values may be regarded as measures of instability within the parameters. As mentioned above, during flight segments in which a parameter is supposed to change (e.g. altitude during ILS or ITO), the standard deviation is not a good measure of system performance, although if rigid standardization of the maneuver is imposed the standard deviations of changing flight parameters may indicate the relative "goodness" of performance. The standard deviations are of great interest, however, in flight segments for which parameters should remain constant. CRUISE, therefore, allows a straightforward interpretation of all six parameter standard deviations. ILS and ITO, as will be seen below, are more problematic. The purpose of assessing the relationship among the parameter standard deviations is similar to the purpose of factor analyzing the visual performance variables as performed in Phase I, namely, to select variables for

further analysis that will be most representative (and least redundant if more than one are chosen) of the "scatter" defined by the variances/ covariances of the variables. There is an important difference between the two sets of analyses, however. Whereas in Phase I the variables were all computed from the same data (where and how long the pilot maintained visual fixation), the variables examined in Phase II were each computed from distinct data: the sampled values for each flight parameter.

Approach

In contrast to the analyses performed in Phase I, the analyses performed in Phase II did not test for difference between maneuvers. The data for each maneuver was analyzed separately, though each maneuver was approached similarly. The maneuvers examined here presumably differ in qualitative ways, for example, "good" pitch standard deviation during ITO may be poor pitch standard deviation during CRUISE. With no method to account for qualitative differences between maneuvers, direct comparisons across maneuvers would have been superficial. There was also another concern that dictated a different approach to the Phase II analyses: it is possible that the relationships among the parameter standard deviations might change across days. For example, it might be that a rested pilot can maintain system performance in all six parameters whereas a fatigued pilot might sacrifice control of some parameters to a certain extent in order to maintain control of other parameters. The correlations among these variables would then be expected to change as a function of fatigue. Note that this was not a concern in Phase I, because, as mentioned above, the different measures of visual performance were all calculated from the same data. The relationships among the Phase I variables would not be expected to vary as a function of maneuver or fatigue, therefore data from each maneuver on each day were pooled in the factor analysis. In the Phase II data, however, each day for each maneuver was examined separately before any pooling was done, and data from different maneuvers were never pooled for reasons discussed above. The data for each day of each maneuver were factor analyzed separately, pooling within maneuvers across days was done where appropriate, and representative variables for each maneuver were then further analyzed for possible across-days effects. Factor rotation was again accomplished using the varimax procedure.

Results and Discussion

The five factor analyses for CRUISE returned virtually identical one-factor solutions. Each of the six parameter standard deviations was strongly correlated with the factor. The range of the factor loadings was from .786 (heading standard deviation on day 1) to .990 (roll standard deviation on day 3). It was therefore evident that the relationships among the variables during CRUISE did not significantly change across days, and the data were pooled in order to provide

a better estimate of these relationships. The factor analysis of the pooled data returned a one-factor solution which is presented in Table 18. This solution accounted for approximately 70% of the variance. Based on this solution, yaw standard deviation was judged to be the variable most representative of the variability of the six flight parameters during CRUISE. Since standard deviations are noted to have non-normal distributions, all standard deviations analyzed in Phase II were transformed to unit normal distributions (z-scores). The transformed yaw standard deviations were analyzed for differences across days by means of ANOVA for a one-factor repeated measures design. The resultant *F*-ratio for the day effect failed to reach significance. The cell means for the untransformed scores are presented in Table 19.

Of the five factor analyses performed for the ILS maneuver, four returned one-factor solutions similar to the solutions for CRUISE: all variables were highly and positively correlated. Day 3, however, returned a two-factor solution. Examination of the unrotated factor loadings revealed that the factor with the largest eigenvalue (4.67, which accounts for about 78% of the variances of six variables) was again similar to the factors associated with CRUISE and the other four days of ILS. The second factor for day 3 accounted for all but 3.5% of the remaining variance.* The rotated solution associated the heading and yaw standard deviations with the second factor. These variables had high negative loadings on the second factor in the rotated solution (-.959 and -.929, respectively), suggesting that on day 3 there may have been extra effort expended to maintain control of headings and yaw, two variables that both refer to the position of the aircraft about the vertical axis, though with different reference points. The possibility that extra effort was expended on heading/yaw control on day 3 is supported by the cell means for these variables (see Table 19), which reveal that performance on both of these variables was better on day 3 than any other day. It is also possible that similar independence in the control of heading and yaw is associated, in general, with the performance of the ILS maneuver but the small N of the present study simply did not allow this phenomenon to be associated with an eigenvalue greater than 1.0 on the other four days. Since the factor solutions across days were not homogeneous, it was not considered appropriate to pool across days, and the selection of representative variables had to be based on the separate day analyses. Pitch standard deviation was chosen as representative of the first factor; this variable had loadings of greater than .9 on factor 7 for each day. Heading standard deviation was chosen as the representative variable for the second factor associated with day 3. The *F*- ratios associated with the day effect for both of these variables failed to reach significance, and the cell means are presented in Table 19.

ITO proved to be even more difficult to analyze than ILS. Three of the five factor analyses again returned similar one-factor solutions, with each variable having high positive loadings on the factor. Days 2 and 4, however, returned two-factor solutions. These two-factor solutions were similar in that the first factors (i.e., the factors with

the largest eigenvalues) in each case were similar to the general pattern of factor loading obtained in CRUISE, ILS, and the other three days of ITO: each variable had high positive loadings on the first factor. Beyond this point, however, the factor solutions were hardly similar at all. There is no obvious explanation for these results other than a general observation that not only is ITO an inherently unstable maneuver, the relationships among the flight parameters during ITO are apparently unstable as well. Since the values for altitude, airspeed, and heading during ITO exhibit vast changes in the process of attaining the desired values for these parameters, they were eliminated from consideration for further analysis of the ITO maneuver. The correlations among pitch, roll, and yaw standard deviations during ITO were examined, and as each of these correlations was found to be essentially zero (see Table 20), all three variables were analyzed as representative of ITO. The F-ratios for the day effect associated with each of the three variables again failed to reach significance, and the cell means are presented in Table 19.

The factor analyses performed in Phase II were directed at assessing the relationships among the flight parameters in each maneuver. These analyses were admittedly based on insufficiently small sample sizes as compared to the number of relationships we attempted to estimate. The factor analyses were primarily used as a tool for selecting representative variables for further analysis. The generality of these relationships can only be confirmed or denied by replication in other data. It is encouraging to note, however, that the objective results of the factor analyses are in concert with the intuitive notions, expressed informally by pilots, of how each maneuver is performed. CRUISE is associated with the maintenance of the status quo and it is generally not too difficult to do so. System stability is relatively simple and can be represented by one factor. ILS is a bit more complicated in that special attention must be devoted to maintaining the proper heading to insure proper alignment with the runway. ITO is even more complicated and is better described as the attainment of aircraft stability rather than the maintenance of stablity. If these intuitive notions are correct, then it is not surprising that CRUISE, ILS, and ITO are best represented by one, two, and three variables respectively. In further support of this point, the correlations among pitch, roll, and yaw standard deviations are presented in Table 20. All the data within each maneuver were pooled in calculating these correlations. Examination of these values reveals that during CRUISE, the three variables are highly correlated. During ILS, the value for pitch and roll remain highly correlated, but the correlation of yaw with both of these values is substantially less than in CRUISE, dropping to more moderate values slightly less than .5. During ITO, however, each of the correlations is essentially zero. The differences in these correlations suggest the increasing complexity of maintaining system stability during CRUISE, ILS, and ITO respectively. It is likely that take-off, straight and level flight, and landing are bound to be part of virtually every flight profile used in further experimentation, and it is hoped that these analyses will help provide a framework for assessing pilot per-

formance during these maneuvers.

As an additional part of Phase II, the relationship between the pilots' visual performance data from Phase I and the system performance variables of Phase II was explored. An ideographic approach was used in this effort, and the relationship between the visual contact with an instrument and the variability of the flight parameter associated with that instrument was examined by computing correlations for each subject on a number of these instrument-flight parameter relationships. A trend of positive correlation would have suggested that instability of a given parameter was associated with an increased monitoring of the associated instrument in an attempt to better control the parameter. On the other hand, a trend of negative correlations would have suggested that the more an instrument was monitored, the greater the stability of the associated parameter. However, the data did not reveal either of those trends. The correlations exhibited a varied assortment of positive, negative, and zero correlations with no apparent pattern. The correlations for four of the relationships are presented on Table 21.

Recommendations and General Discussion

Due to the small N employed in this study and the ability of factor analytic-techniques to capitalize on spurious correlations, we strongly recommend that the factor analysis results be tested with confirmatory factor analysis in data from other studies. The following findings were particularly important in the present research and, if confirmed, will have significant applicability to future analyses of helicopter pilots performance:

(1) Scan rate, percent of time, and percent of looks are variables that are highly correlated in visual performance data, and these variables are essentially uncorrelated with mean and median dwell times.

(2) The standard deviations of all six flight parameters during CRUISE are highly and positively correlated.

(3) Pitch and roll standard deviations are highly correlated during ILS, as are heading and yaw standard deviations, but the correlations between the two sets of variables is only moderate.

(4) Pitch, roll, and yaw standard deviations during ITO are essentially uncorrelated

If the generality of these findings is confirmed, then the following recommendations are applicable to future analyses:

(1) The scan rate is the preferred measure of the relative importance of an instrument in visual performance data, because it does not impose an artificial ceiling on the

data in contrast to variables expressed as percent. The scan rate values should be tested for departure from normality before further analyses are conducted.

(2) The choice between mean and median dwell time should be predicated on an assessment of the skewness of the values on which they are based. The median is generally the preferred value if the underlying distribution is significantly skewed from normality.

(3) Assessment of system performance during CRUISE, ILS, and ITO should involve the minimum number of values required to adequately represent orthogonal factors associated with each maneuver. Analysis of more than the minimum is not only redundant, but serves to inflate the alpha risk as well.

(4) Standard deviations are noted to have non-normal distributions; these variables should either be transformed to normality before analysis or a nonparametric test should be used.

An issue ubiquitous in statistical analyses is relevant to the recommendations presented above: should separate univariate tests be used or should variables be combined for a multivariate analysis? This issue is still debated among statisticians, and we certainly cannot provide a definitive answer here. A useful rule of thumb, however, is to use univariate tests for univariate hypotheses, and multivariate tests for multivariate hypotheses. Experienced investigators may be quite able to form multivariate hypotheses to be tested in pilot performance studies. It is often the case, however, that univariate hypotheses are easier to formulate and easier to understand. The relative strengths and weaknesses of univariate vs. multivariate tests of hypotheses are discussed in most statistics reference books.

In the process of conducting the present research, there were several issues that were encountered but not directly addressed by our analyses. Foremost of these issues was the question of how findings from visual performance data and from concurrent system performance data may be integrated in a meaningful way. A similar issue is how data based on the pilot's control inputs should be interpreted in light of system performance findings. It can be argued that both visual performance data and control input data are purer measures of the pilot's behavior, in that they represent what the pilot actually does, whereas the system performance data presumably reflect the outcome of what the pilot did. It seems apparent that the latter information is more pertinent to the practical questions at hand--in this case the effects of extended flight schedules. If the pilot's visual behavior or control behavior is found to change over time, but there is no concurrent change in system performance, there is obvious difficulty in intepreting these results. In the absence of degradation in system performance, it would be difficult to argue that the pilot's per-

formance degraded, although it may well have changed. These changes could be due to a change in strategy on the pilot's part, boredom with the experiment, or some cyclicity of unknown origin in the pilot's behavior. These observations suggest a hierarchy in the levels of analysis of pilot performance in which findings at one level must be interpreted on light of findings at another level. If system performance changes without concurrent change in visual or control behavior, then the pilot apparently continued to do the same things he did all along, but simply became less effective over time. On the other hand, if visual performance or control inputs change without concurrent change in system performance, then the pilot may have, for some reason, changed strategies but remained just as effective. It is possible, of course, that changes in visual performance and/or control behavior may serve as predictors of future system performance changes, but such predictiveness has not been documented.

In light of the negative findings with respect to across-days effects in both this study and previous studies, it may be concluded that pilot performance of simple, well-practiced maneuvers does not appear to appreciably change over the course of a five day extended flight schedule. It should be noted, however, that in combat conditions the pilot's tasking will typically include more than the performance of simple maneuvers. A helicopter pilot must often do more than simply fly the helicopter; he will often be required to simultaneously perform additional tasks such as threat evasion, navigation, and the monitoring of other displays such as radar warning receives. These additional tasks suggest the proper direction for future investigations of helicopter pilot fatigue. Numerous studies have examined the effects of fatigue in automobile drivers and fixed-wing pilots, and the general finding is that tasks such as driving or flying are highly resistant to the effects of fatigue. The current direction in such research is to impose secondary tasking on the subjects, and it has been suggested that performance of secondary tasks may be more sensitive to typical variable of interest in field research than is the primary task (e.g.Hart and Simpson, 1976). The fact that helicopter pilots often required to perform secondary tasking as they fly affords new possibilities in assessing the effects of fatigue in helicopter pilots. Primary task performance will remain the subject of greatest concern, but the use of the secondary tasking paradigm will allow a broader assessment of the totality of helicopter pilot performance.

References

Hamilton, B.E., Folds, D.J., and Simmons, R.R. (1982). Performance impact of current United States and United Kingdom chemical defense ensembles. USAARL Report No. 82-9. Ft. Rucker, AL: U.S. Army Aeromedical Research Laboratory.

Hart, S.G., and Simpson, C.A. (1976). Effects of linguistic redundancy on synthesized cockpit working message comprehension and concurrent time estimation. 12th Annual Conference on Manual Control, Coordinated Science Laboratory (NASA Tmx 73, 170), pp. 309-321.

Lees, M.A., Simmons, R.R., Stone, L.W., and Kimball, K.A. (1978). Changes in the rotary wing aviator's ability to perform an uncommon low altitude rearward hover maneuver as a function of extended flight requirements and aviator fatigue. In S.C. Knapp (Ed.) Operational Helicopter Environmental Medicine. London: Teachnical Editing and Reproduction, Ltd. (NATO/AGARD CP-255).

Krueger, G.P., Armstrong, R.N., and Cisco, R.R. (1980). Aviator performance in week-long extended flight operations in a helicopter simulator. In R. Auffret (Ed.) Aircrew Safety and Survivability. London: Technical Editing and Reproduction, Ltd. (NATO/AGARD CP-286).

Krueger, G.P. and Fagg, J.N. (1981). Aeromedical factors in aviator fatigue, crew work/rest schedules and extended flight operations: An annotated bibliography. (USAARL Report No. 81-1) Ft. Rucker, AL: U.S. Army Aeromedical Research Laboratory.

Myers, J.E. (1979) Fundamentals of Experimental Design. Boston: Allyn and Bacon.

Perry, I.C. (Ed.) (1974). Helicopter aircrew fatigue. AGARD Advisory Report No. 69. London: Harford House.

Simmons, R. Kimball, K., and Diaz, J. (1976). Measurement of aviator visual performance and workload during helicopter operations. (USAARL Report No. 77-4) Ft. Rucker, AL: U.S. Army Aeromedical Research Laboratory.

Simmons, R., Lees, M., and Kimball, K. (1978). Visual performance/workload of helicopter pilots during instrument flight. (USAARL Report No. 78-6) Ft. Rucker, AL: U.S. Army Aeromedical Research Laboratory.

TABLE 1

Percent of Total Time for Each Instrument

INSTRUMENT	ABBREVIATION	% TOTAL TIME
Altimeter	ALT	4.0
Vertical Speed Indicator	VSI	5.4
Artificial Horizon	AH	22.4
Radio Magnetic Indicator	RMI	24.5
Omni-bearing Selector	OBS	13.6
Airspeed Indicator	AS	5.4
Turn & Bank Indicator	T&B	3.7
Compass	CMPS	*
Clock	CLK	.7
Fire Warning Light	FIRE	*
Tachometer	RPM	.6
Torque	TQ	.5
Gas Producer	GSPD	.3
Exhaust Gas Temperature	EXTP	.1
Master Caution Light	WINGl	*
Fuel Gauge	FUEL	.2
Oil Gauge	OIL	.2
Transmission Gauge	TRNS	.2
Electrical Load Meters	ELEC	.1
Co-pilot's Altimeter	2ALT	*
Co-pilot's VSI	2VSI	*
Co-pilot's AH	2AH	*
Co-pilot's RMI	2RMI	*
Co-pilot's AS	2AS	*
Co-pilot's OBS	2OBS	*

* - Less than one half of one percent

TABLE 2

Dependent Variables for Visual Performance Data

ABBREVIATION	NAME	EXPLANATION
1. #LKS	number of looks	total number of eye fixations
2. %LKS	percent of looks	#LKS/total #LKS
3. MEAN	mean dwell time	average duration of fixations
4. MED	median dwell time	median of the dwell times
5. RATE	scan rate	how often the area was fixated
6. %TT	percent of total time	percent of visual time spent fixated on the area
7. CF	cost factor	(%LKS + %TT)/2; percent of workload

TABLE 3

Mean Dwell Times for the Seven Primary Instruments (milliseconds)

OBS	697.0
RMI	620.9
AH	555.0
VSI	353.4
AS	511.2
ALT	507.9
T&B	429.8

TABLE 4

Rotated Two Factor Solutions from Factor Analysis of Seven Department Variables

Instrument	Factor	#LKS	%LKS	MEAN	MED	RATE	%TT	CF	% Variance
ALT	1	.740	.977	.094	.154	.975	.922	.963	.652
	2	-.193	-.221	.893	.862	-.301	-.022	-.113	.247
VSI	1	.837	.931	.258	.359	.947	.892	.919	.787
	2	.236	.336	.945	.902	.230	.395	.369	.145
AH	1	.651	.953	.164	.179	.974	.932	.951	.675
	2	.397	.242	.913	.917	-.069	.322	.252	.207
RMI	1	.605	.976	.005	.099	.965	.942	.970	.600
	2	-.116	.138	.957	.927	-.082	.249	.198	.257
AS	1	.614	.958	.152	.281	.968	.936	.954	.679
	2	.219	.196	.959	.928	.089	.277	.247	.197
T&B	1	.824	.983	.081	.147	.989	.962	.984	.678
	2	.177	.087	.964	.959	.017	.162	.123	.247
Averages	1	.711	.963	.125	.203	.969	.931	.956	.678
	2	.184	.129	.938	.915	-.019	.230	.179	.216

Average variance accounted for by Factor 1 + Factor 2 =.894

TABLE 5

Three Zones of the Pilot's Visual Field

Zone 1	AH
	RMI
	T&B
Zone 2	ALT
	VSI
	AS
Zone 3	OBS
	All other instruments
	All other visual areas

TABLE 6

Rotated Three-Factor Solution from Factor Analysis of the Seven Primary Instruments

	ALT	VSI	AH	RMI	OBS	AS	T & B
Factor 1	.093	.843	-.781	.348	.791	-.355	-.108
Factor 2	-.059	.116	.161	.783	-.183	-.027	.918
Factor 3	.910	-.173	.177	-.296	-.325	.714	.107

TABLE 7

%TT For Zone 1 Instruments During ITO

Subject	T&B	AH	RMI	Zone 1
1	8.0	27.5	23.3	58.8
2	8.6	34.0	23.7	66.3
3	3.4	25.5	41.8	70.7
4	15.9	9.2	46.7	71.7
5	3.5	33.7	27.0	64.2
6	4.6	34.4	35.0	74.0
Total	7.6	26.8	33.4	67.8

TABLE 8

Percent of Total Time for Each Maneuver

INST	ITO	CRUISE	ILS
ALT	4.2	6.4	3.0
VSI	3.5	3.3	6.7
AH	26.8	28.5	19.1
RMI	33.4	18.2	24.6
OBS	1.7	1.1	21.2
AS	5.1	9.9	3.7
T&B	7.6	4.8	2.3
All Other Instruments	4.1	4.5	2.1

TABLE 9

ANOVA - ALT Scan Rate

SV	df	SS	MS	F	P less than
Total	89	1512.259	-	-	-
Maneuvers	2	406.691	203.345	13.51	.05
Days	4	56.032	14.008	0.78	N.S.
Subjects	5	157.088	31.418		-
Man. x Day	8	67.265	8.408	1.06	N.S.
Man. x Sub.	10	150.053	15.054	-	-
Day x Sub.	20	357.086	17.854	-	-
Man. x Day x Sub.	40	317.553	7.939	-	-

TABLE 10

ANOVA - VSI Scan Rate

SV	df	SS	MS	F	P less than
Total	89	1444.954	-	-	-
Maneuvers	2	172.142	86.071	7.76	.05
Days	4	17.003	4.251	0.18	N.S.
Subjects	5	211.326	42.265	-	-
Man. x Day	8	16.075	2.009	0.18	N.S.
Man. x Sub	10	110.860	11.086	-	-
Day x Sub	20	462.886	23.144	-	-
Man. x Day x Sub	40	454.661	11.367	-	-

TABLE 11

ANOVA - OBS Scan Rate

SV	df	SS	MS	F	P less than
Total	89	8275.027	-	-	-
Maneuvers	2	4889.152	2444.576	32.48	.05
Days	4	20.001	5.000	.14	N.S.
Subjects	5	493.242	98.648	-	-
Man. x Day	8	54.326	6.791	0.20	N.S.
Man. x Sub	10	752.638	75.264	-	-
Day x Sub	20	725.610	36.280	-	-
Man. x Day x Sub	40	1340.059	33.501	1	1

TABLE 12

ANOVA - AS Scan Rate

SV	df	SS	MS	F	P less than
Total	89	2476.259	-	-	-
Maneuvers	2	917.308	458.654	24.80	.05
Days	4	117.339	29.335	1.87	N.S.
Subjects	5	135.386	27.077	-	-
Man. x Day	8	133.996	16.750	0.99	N.S.
Man. x Sub	10	184.936	18.494	-	-
Day x Sub.	20	313.438	15.672	-	-
Man. x Day x Sub.	40	673.857	16.846	-	-

TABLE 13

ANOVA - T & B Scan Rate

SV	df	SS	MS	F	P less than
Total	89	4797.580	-	-	-
Maneuvers	2	808.215	404.107	4.47	.05
Days	4	49.929	12.482	0.32	N.S.
Subjects	5	1225.658	245.132	-	-
Man. x Day	8	99.686	12.461	0.54	N.S.
Man. x Sub.	10	909.637	90.364	-	-
Day x Sub.	20	783.245	39.162	-	-
Man. x Day x Sub.	40	927.211	23.180	-	-

TABLE 14

Summary Of Significant Differences Between

Maneuvers For Each Instrument (Scan Rate)

ALT	Cruise higher than ITO or ILS, ITO higher than ILS
VSI	ILS higher than CRUISE or ITO
AH	None
RMI	None
OBS	ILS higher than Cruise or ITO
AS	CRUISE higher than ITO or ILS
T&B	CRUISE higher than ILS

TABLE 15

ANOVA - OBS Mean Dwell Time

SV	df	SS	MS	F	P less than
Total	89	6992194.000	-	-	-
Maneuvers	2	2625380.000	1312690.000	14.20	.05
Days	4	80405.000	20101.250	0.31	N.S.
Subjects	5	265917.000	53183.398	-	-
Man. x Day	8	108919.000	13614.875	0.33	N.S.
Man. x Day	10	924491.000	92449.102	-	-
Day x Sub.	20	1316811.000	65840.547	-	-
Man. x Day x Sub.	40	1670271.000	41756.773	-	-

TABLE 16

ANOVA - VSI Mean Dwell Time

SV	df	SS	MS	F	P less than
Total	89	3763450.000	-	-	-
Maneuvers	2	388644.000	194322.000	7.20	.05
Days	4	230605.000	57651.500	1.39	N.S.
Subjects	5	520958.000	104191.602	-	-
Man. x Day	8	344192.000	43024.000	1.45	N.S.
Man. x Day	10	266056.000	26605.600	-	-
Day x Sub.	20	828232.000	41411.602	-	-
Man. x Day x Sub.	40	1184762.000	29619.051	-	-

TABLE 17

ILS %TT

Subject	AH	RMI	OBS
1	12.4	21.9	29.5
2	6.9	24.2	31.6
3	9.1	32.2	22.3
4	33.9	23.8	11.4
5	20.4	24.7	16.6
6	38.8	20.8	10.5
Total	19.1	24.6	21.2

TABLE 18

Factor Analysis Solution for CRUISE (Days Pooled)

Variable	Factor Loading
Altitude S.D.	0.663
Airspeed S.D.	.876
Heading S.D.	.821
Pitch S.D.	.873
Roll S.D.	.853
Yaw S.D.	.916
%Variance accounted for =	.696

TABLE 19

Cell Means of the Variables Selected for Analysis

Maneuver	Variable	Day 1	2	3	4	5
CRUISE	Yaw S.D.	0.51	0.38	0.41	0.37	0.65
ILS	Pitch S.D.	0.69	0.68	0.57	0.50	0.61
	Heading S.D.	5.96	4.22	2.95	3.78	3.00
ITO	Pitch S.D.	1.30	1.25	1.78	1.53	1.66
	Roll S.D.	2.06	2.29	1.89	2.12	2.38
	Yaw S.D.	3.59	2.54	2.69	2.30	2.38

TABLE 20

Correlations Among Pitch, Roll, and Yaw Standard Deviations for Each Maneuver

CRUISE		PITCH	ROLL	YAW
	Pitch	1.0	.676	.724
	Roll	.676	1.0	.867
	Yaw	.724	.867	1.0

ILS		PITCH	ROLL	YAW
	Pitch	1.0	.796	.468
	Roll	.796	1.0	.430
	Yaw	.468	.480	1.0

ITO		PITCH	ROLL	YAW
	Pitch	1.0	.054	.140
	Roll	.054	1.0	-.120
	Yaw	.140	-.120	1.0

TABLE 21

Correlations Between Visual Performance and System Performance

Relationship	Subject	Correlation
Altimeter scan rate & altitude	1	-.838
Standard deviation during cruise flight	2	.156
	3	.774
	4	.242
	5	.285
	6	-.423
Airspeed indicator scan rate & airspeed standard deviation during cruise flight.	1	-.511
	2	-.009
	3	.393
	4	-.336
	5	.546
	6	-.758
Attitude indicator scan rate & pitch standard deviation during instrument take-off	1	.537
	2	.501
	3	-.326
	4	.278
	5	.462
	6	-.308
Attitude indicator scan rate and roll standard deviation during instrument take-off	1	.754
	2	.441
	3	-.218
	4	.596
	5	.831
	6	-.916

END

FILMED

3-85

DTIC